Field Calculation in Models of Man in the Near-Field of Antennas

G. Schaller, R. Engelbrecht, J. Erb.

Laboratories for High Frequency Technology (LHFT),
University Erlangen - Nürnberg, Cauerstraße 9, 91058 Erlangen, Germany.

ABSTRACT

For two examples the electromagnetic field is calculated inside and in the vicinity of properly modelled man in the near-field of antennas.
The first example illustrates the SAR - distribution in a medical attendant near a deep hyperthermia system, whereas in the second example fields are calculated in a human head exposed to hand-held E-net phones. Both cases are investigated applying a 3-D field calculation program based on a finite integration algorithm.

INTRODUCTION

It is only lately that it is possible to calculate the electromagnetic field inside and near complex biological tissues. Proper algorithms and powerful computers are necessary to handle problems of complicated structured models in the near-field of antennas. Such calculations are mostly necessary in order to judge whether a specific device or procedure is save and within the limits of safety standards or whether it may cause health hazards to people involved with.
The reason to do sophisticated calculations instead of measurements is that it is rather impossible to perform detailled experiments inside the human body or even in realistically shaped and structured 3-D man models. Despite the fact that many papers have been published during the last few years dealing with the energy deposition in man exposed to high frequency or microwave fields (see e.g. [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11]), potential health hazards for medical attendants near deep hyperthermia systems have not been investigated yet. So our first example deals with the exposure a medical attendant suffers during the hyperthermia treatment of patients with deep-seated tumors.
In the second example we investigate the fields and SAR-distributions in proper models of the human head exposed to hand-held E-net phones. We also consider this case, because nobody may guarantee a proper use of such a phone in all cases, e.g. when in the hands of children.
In both cases the field evaluation program **MAFIA** (**MA**xwell's equations using the **F**inite **I**ntegration **A**lgorithm) [12] is applied to numerically calculate the EM-fields as well as the SAR-distributions.

EXAMPLE I : MODEL & SIMULATIONS

Hyperthermia treatment of patients with deep-seated tumors have become clinical routine throughout the last decade. The most often used regional hyperthermia system is the BSD-2000™ in connection with a Sigma 60™ applicator (BSD-2000™ and Sigma 60™ are trademarks of BSD Medical Corporation, Salt Lake City, Utah). This ring applicator consists of an annular phased array with 8 equidistant dipoles grouped concentrically around a water bolus and the patient. The antennas are driven at a variable frequency between 60 MHz and 120 MHz. The maximum output power of the system is 2000 W.
By reasons of electromagnetic compatibility, the whole system setup including the patient and often also a medical attendant is hermetically surrounded by a shielded room. This room can be considered as a "dielectrically loaded" resonator stimulated by the hyperthermia system itself. Unfortunately, this resonator has many eigenfrequencies within the frequency band of the hyperthermia system.
So it is possible that the operating frequency may coincide with the resonance frequency and that the attendant is located in a maximum of the E-field. However, in contrast to the patient, the medical attendant must not be exposed to excessive electromagnetic fields.

TU 4E

CH3577-4/95/0000-0291$01.00 © 1995 IEEE

A typical structure of the model is given in Figure 1.

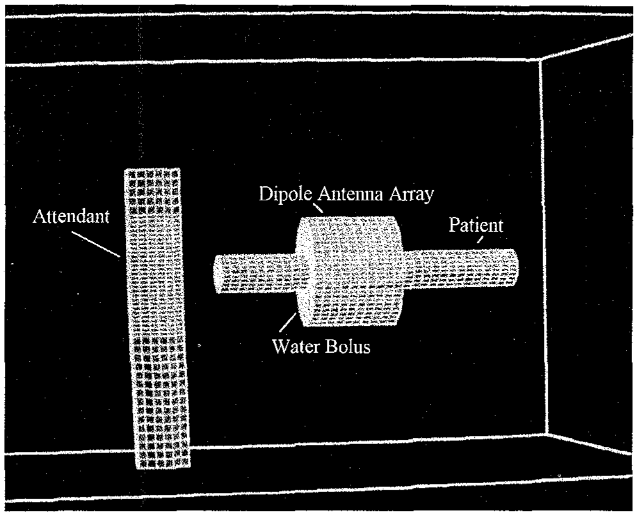

Figure 1: *Model of the room with patient, hyperthermia system and medical attendant.*

In a room with dimensions: 3.2 m x 3.2 m x 2.4 m and electrical conductive walls the patient as well as the attendant are modelled in this simple case as dielectric cylinders. A water bolus filled with deionized water is placed around the horizontally oriented patient. Other parts of the system which mostly consist of plastic materials with low permittivity are neglected.
The dipoles of the applicator here are approached to be elementary dipoles, because we are not interested in a fully detailled field distribution in the patient. To obtain unfavourable frequencies with relatively high SAR-values in the attendant, for a given geometrical situation the following procedure is applied:
A Gaussian shaped pulse is stimulating the dipoles. As a response function the time dependent electrical field in one eye of the attendant is calculated and observed. Applying FFT to the response function finally delivers the frequency dependent transfer function from the dipoles to one eye of the attendant.

RESULTS

Figure 2 shows the stimulus of the dipoles. Figure 3 describes the system response in an eye of the attendant and clearly demonstrates that in this case several eigenfrequencies of the resonator are stimulated with loaded Q's remarkably greater than 1, despite of the losses of the patient and the attendant. This leads to a field enhancement and a potential danger for the attendant. The frequency dependent power transfer function to an eye of the attendant reveals several resonance frequencies which all disappear if the walls are coated with an absorbing material, except the resonance of the water bolus at 118 MHz.

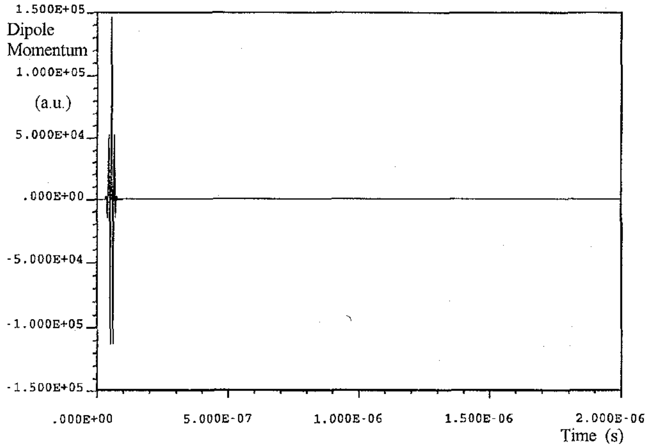

Figure 2: *Stimulus of the dipoles.*

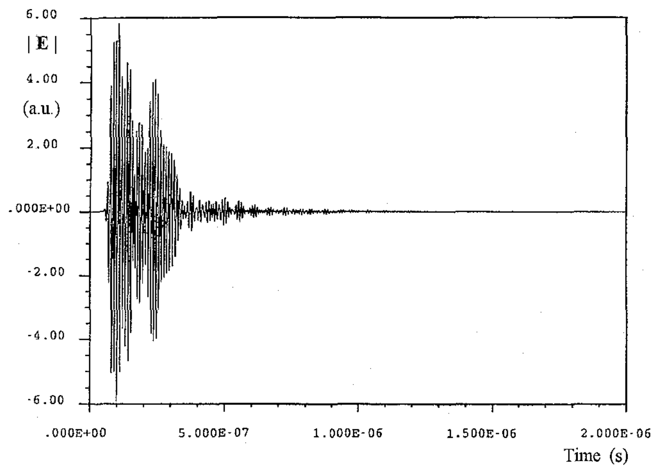

Figure 3: *System response in an eye of the attendant.*

For the specific geometrical situation of this case, Figure 4a shows the electric energy density near the attendant and Figure 4b the absorbed power density inside the attendant at 101 MHz, where the transfer function has its global maximum.
The maximum SAR values are in the area of the feet with values of 7.1 W/kg, but also a local maximum in the head can be found with 2 W/kg.
The main conclusions are the following:

- The SAR-values in the attendant are not alarming and can be tolerated for the specific geometrical configurations of our calculations.

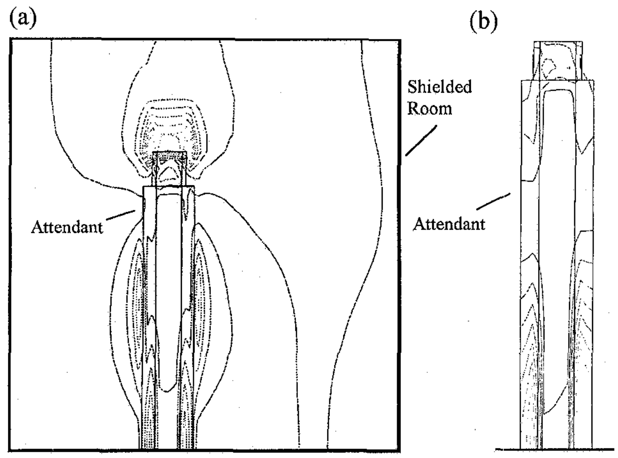

Figure 4: *(a) Electric energy density near the attendant and (b) absorbed power density inside the attendant both at 101 MHz.*

- The worst case for an attendant depends on many parameters, mainly his position and also the amplitudes and phases of the dipoles. The global worst case cannot be found easily.
- In any case, applying absorbing walls avoids field enhancement at or near resonance frequencies and thus reduces SAR-values in the medical attendant.

EXAMPLE II : MODEL & SIMULATIONS

The model of the human head has the following features: Thin skull surrounding a homogeneous brain tissue, eyes in bone sockets, cavities of mouth and nose are included in the model, also a frontal sinus, and neck of muscles including spine and trachea.
The electromagnetic properties of different tissues at 1.8 GHz are given in the following table:

Tissues	rel. Permittivity	Conductivity
Bone	5.5	0.15 S/m
Brain	34	1.0 S/m
Eye	40	1.5 S/m
Muscle	50	2 S/m

The hand-held phone consists of a metal box with a $\lambda/4$ monopole at 1.8 GHz. A cosine current distribution in the antenna is simulated splitting it into eight successive elementary dipoles with different currents. The total radiated power in our calculations is 1W.
A cut through the 3D-model of the human head without the phone is given in Figure 5. The 3D-model of an improperly held phone in direct proximity to the eyes is shown in Figure 6.

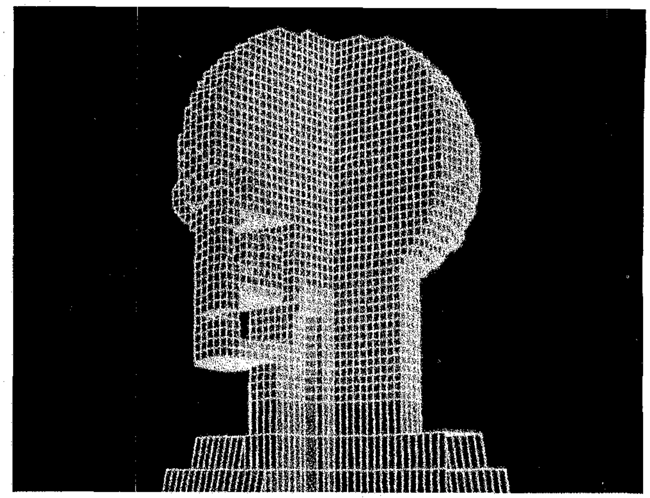

Figure 5: *Cut through the model of the human head.*

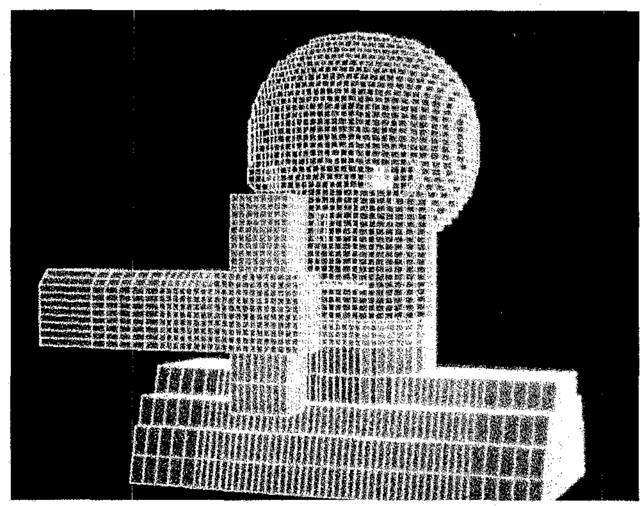

Figure 6: *3-D model of improperly held phone in direct proximity to one eye.*

The grid inside the head is continued outside and the whole model is hermetically surrounded by an absorbing boundary.
First, a Gaussian pulse is applied as stimulus in the time-domain solver with useable frequencies ranging from 1.1 GHz up to 2.5 GHz. Applying a FFT, the frequency-dependent transfer function to distinct points inside the head, e.g. ear or eye, can be calculated to detect possible resonance frequencies.
Second, a sinusoidal stimulus at 1.8 GHz is applied to evaluate the fields and the SAR distribution in the model.

RESULTS

A few important results of our simulations with a spatial resolution of 5 mm are the following:

'Hot spots' either in the ear or in the eye are to be expected. The maximum SAR values ($\approx$ 3 W/kg) indicate that there is no danger because of thermal effects if the radiated power does not exceed 1 W and if a temperature enhancement of 1 K is tolerated. The calculated SAR values extremely depend on the handling of the device. But no resonance effects have been detected.

Figure 7 shows the SAR distribution in a vertical cut between ear and eye if the phone is held correctly, whereas in Figure 8 the SAR distribution is given in a horizontal view through the eyes if the device is held in front of one eye.

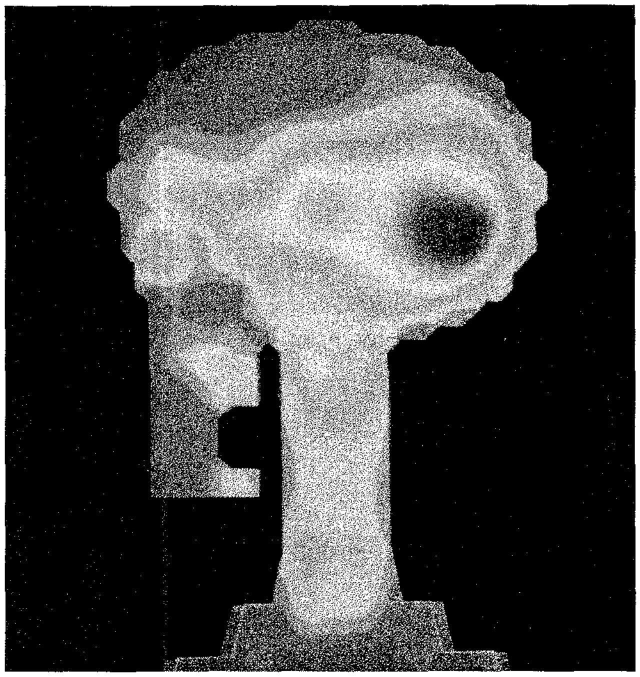

Figure 7: *SAR-distribution in a vertical cut.*

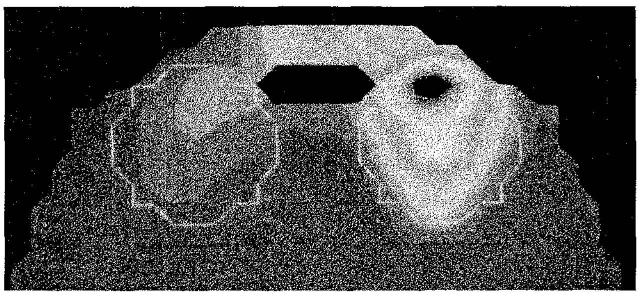

Figure 8: *SAR-distribution in a horizontal cut, while the phone is held in front of one eye.*

REFERENCES

[1] **R.J. Spiegel**. "A Review of Numerical Models for Predicting the Energy Deposition and Resultant Thermal Response of Humans Exposed to Electromagnetic Fields." *IEEE Trans. Microwave Theory Tech.* **32**(8), 730 (1984).

[2] **H. Massoudi**, **C.H. Durney** and **M.F. Iskander**. "Limitations of the Cubical Block Model of Man in Calculating SAR Distributions." *IEEE Trans. Microwave Theory Tech.* **32**(8), 746 (1984).

[3] **D.T. Borup** and **O.P. Ghandi**. "Fast-Fourier-Transform Method for Calculation of SAR Distributions in Finely Discretized Inhomogeneous Models of Biological Bodies." *IEEE Trans. Microwave Theory Tech.* **32**(4), 355 (1984).

[4] **M.A. Stuchly**, **R.J. Spiegel**, **S.S. Stuchly** and **A. Kraszewski**. "Exposure of Man in the Near-Field of a Resonant Dipole: Comparison Between Theory and Measurements." *IEEE Trans. Microwave Theory Tech.* **34**(1), 26 (1986).

[5] **C.-H. Tsai**, **H. Massoudi**, **C.H. Durney** and **M.F. Iskander**. "A Procedure for Calculating Fields Inside Arbitrarily Shaped, Inhomogeneous Dielectric Bodies Using Linear Basis Functions with the Moment Method." *IEEE Trans. Microwave Theory Tech.* **34**(11), 1131 (1986).

[6] **M.F. Iskander**, **S.C. Olson** and **J.F. McCalmont**. "Near-Field Absorption Characteristics of Biological Models in the Resonance Frequency Range." *IEEE Trans. Microwave Theory Tech.* **35**(8), 776 (1984).

[7] **R.F. Cleveland** and **T.W. Athey**. "Specific Absorption Rate (SAR) in Models of the Human Head Exposed to Hand-Held UHF Portable Radios." *Bioelectromagnetics* **10**, 173 (1989).

[8] **N. Kuster** and **Q. Balzano**. "Energy Absorption Mechanism by Biological Bodies in the Near Field of Dipole Antennas Above 300 MHz." *IEEE Trans. Veh. Technol.* **41**(1), 17 (1992).

[9] **H. Garn**, **H. Kremser**, **R. Kremser** and**G.Neubauer**. "Beurteilung der Strahlenexposition bei D-Netz-Hand-Mobilfunktelefonen." *Frequenz* **48**(7-8), 153 (1994).

[10] **H.-R. Chuang**. "Human Operator Coupling Effects on Radiation Characteristics of a Portable Communication Dipole Antenna." *IEEE Trans. Microwave Theory Tech.* **42**(4), 556 (1994).

[11] **J. Toftgård**, **S.N. Hornsleth** and **J. Bach Andersen**. "Effects on portable Antennas of the Presence of a Person." *IEEE Trans. Microwave Theory Tech.* **41**(6), 739 (1993).

[12] **Weiland et al**. "Finite Integration: Ein universell anwendbares Verfahren zur Berechnung elektromagn. Felder." *VDE-Fachbericht* **45**, 109 (1993).